United States Department of Agriculture

Agricultural Research Service

Administrative Management
North Atlantic Area
Administrative Office

600 East Mermaid Lane
Philadelphia
Pennsylvania
19118

MAR 14 1995

SUBJECT: Transmittal of Final Report and Publications

TO: National Agricultural Library
Acquisitions and Serials Branch

FROM: Regina M. Herchak Regina M. Herchak
Authorized Departmental Officer

Enclosed please find the Final Report for Trust Fund Cooperative Agreement No. 58-1902-4-017, as required by Directive 282.1, Extramural Research - Cooperative Agreements. There were no Publications or Report of Inventions and Subawards, (DD-882) under this agreement. Should you have any questions concerning this information, please feel free to contact Lisa Botella at (215) 233-6555.

cc:
R. Schnable, PSWM
A. Smith, PSWM
File

A Final Report

Submitted by:

United States Department of Agriculture

Agricultural Research Service

Pasture Systems and Watershed Management Research Unit

Plant Nutrient Export from an Agricultural Watershed with Extensive Streambank Grazing

Submitted to:

Chesapeake Bay Program

Nonpoint Source Subcommittee Research

Submission Date:

January 25, 1995

Principal Investigators:

Ronald R. Schnabel, Research Soil Scientist, Pasture Systems and Watershed Management Research Unit, USDA-ARS, University Park, PA 16802

(814) 863-8760

and

Robert F. Carline, Leader, Pennsylvania Cooperative Fish and Wildlife Research Unit

University Park, PA 16802

(814) 865-4511

Table of Contents

INTRODUCTION: Riparian zone management is an important component of efforts to reduce non-point source pollution in the Chesapeake Bay watershed. Near-stream management is encouraged in programs such as Maryland's Green Shores, and Virginia's Chesapeake Bay Preservation Act among other state and federal programs. Streambank fencing, to keep grazing animals out of near-stream areas, and streambank stabilization, to control erosion, are among recommended practices. A number of governmental agencies have cost-share programs to encourage land owners to implement these practices, and private groups such as Trout Unlimited also provide funds and expertise to landowners. While many publications give detailed technical guidance and information concerning sources of funding, there are few studies of eastern watersheds in which the effects of streambank fencing and stabilization on nutrient export have been well documented, leaving water quality improvements resulting from the practice largely anecdotal.

Lietman et al. (1983) documented plant nutrient losses from pastures in the Pequea Creek basin of southeast Pennsylvania. They measured discharges of suspended solids and plant nutrients from sub-watersheds with forest, corn culture, pasture and residential as primary land uses. The pastured sub-watershed exported the greatest quantities of suspended solids and total phosphorus. The ~2450 kg/ha of suspended solids was 50 times more than that exported from the forested watershed. Greater than 85% of the suspended solids loss occurred during storm events. They concluded that eroding streambanks in the pasture were a large source of sediment, and that cattle walking through the stream loosened additional sediment making it available for transport. The phosphorus yield of 15.8 kg/ha from pastures was 150 times that from the forested site. Stormflow contained twenty-three percent of total phosphorus yield. The total nitrogen yield of 42 kg/ha from the pasture site was more than twice that from the forested site. Organic nitrogen made up about two-thirds of the total and one half of the nitrogen was contained in stormflow. This contrasts with the other sites where nitrate contained in baseflow was the principal form of nitrogen exported from the watershed. No streambank improvements were implemented on the watershed.

Owens et al., (1989) measured sediment and chemical concentrations in a stream draining a 26-ha unimproved pasture on the Appalachian Plateau at Coshocton, Ohio. A 5.2-ha strip of predominantly mixed hardwoods bordered most of the stream. The study period included 2 yrs with no grazing, 3 yrs with summer only grazing and 6 yrs where a herd of 17 spring calving Charolais cows grazed the pasture year-round and was fed hay, grown elsewhere on the station, during winter months. Inorganic N and P concentrations were unchanged by increasing cattle occupancy. Average soluble organic N concentrations, however, did increase from 0.6 to 1.2 mg/l for the summer only and to 2.7 mg/l during year-round grazing periods. This increase in organic

nitrogen might be interpreted as conversion of inorganic nitrogen to organic nitrogen in the riparian forest. However, since the cattle were not fenced out of the woodland for this study it is more likely a reflection of the nitrogen forms predominant in urine and feces. Sediment transport showed the greatest impact of grazing pressure. Average annual sediment transport from the watershed increased from 223 kg/ha for the ungrazed period to 2088 kg/ha for year-round grazing. Following this study, a fence was constructed around the woods to keep the cattle out of the woods and stream. During the next four years, the major change measured as a result of the fencing was a 40% reduction in sediment transport (Owens, 1993).

Rinne (1988) reviewed results of grazing-fisheries interaction studies in the West. He noted that while the consensus among fisheries biologists was that grazing was detrimental to salmonid fisheries, results of some studies were inconsistent or inconclusive. Rinne (1988) argues that the inconsistency results from inappropriate design. Typically, researchers compared conditions in fenced and unfenced sections where the influence of upstream unfenced sections could not readily be separated from the effects of fencing. Rinne (1988) concludes that grazing-fisheries interaction studies need to be designed so that the watershed is the basic sampling unit.

The Centre County Conservation District, in cooperation with the Pennsylvania Cooperative Fish and Wildlife Research Unit and the Spring Creek Chapter of Trout Unlimited, in 1991 initiated a demonstration project to reduce sediment loads in Spring Creek, Centre County, Pennsylvania. The project was undertaken to document improvements in water quality and stream fauna resulting from fencing riparian areas and stabilizing streambanks. During the first year of this project, monitoring stations were established on three tributaries (Figure 1), two of which flow through intensively farmed lands. Data collection included continuous measurement of streamflow and regular sampling for total suspended solids. Stream substrate composition, benthic macroinvertebrates, and fish communities were characterized at several sampling stations in each tributary. A streambank survey conducted in 1989 revealed no badly eroded banks in the Spring Creek basin, where there is little agriculture, 2.2 km of severely eroded streambank in the Cedar Run basin, and 3.4 km of eroded streambank in the Slab Cabin Run basin. The amount of eroded streambank was a function of the amount of dairy pasture in the riparian zone of each basin. The median daily concentration of total suspended solids (TSS) ranged from 25 to 48 mg/L and total annual sediment load ranged from 172 to 253 metric tons in Cedar Run and Slab Cabin Run (Wohl and Carline, 1995). In contrast, the Spring Creek sub-basin had no riparian grazing, median daily TSS was 5 mg/L and total annual sediment load was 86 metric tons. The difference in total sediment load is even more striking considering that total discharge from Spring Creek was 50% greater than from Cedar Run and five times greater than from Slab Cabin Run. If the

extent of erosion in the three basins was similar one would expect a much greater sediment load from Spring Creek than from the other two basins, the opposite of what was observed.

Fencing and bank stabilization began in the Slab Cabin Run sub-watershed in 1992. By fall 1993, over 80% of the eroded streambank in Slab Cabin Run will have been stabilized by installation of bank riprap, rock-lined crossings for animals and streambank fencing. In the fall of 1994, efforts will shift to bank stabilization in Cedar Run, the other sub-basin that has extensive streambank erosion. Plant nutrient analyses will be included in the post-treatment monitoring of the Cedar Run sub-watershed

OBJECTIVE: A component of water quality not currently addressed by this research is the quantity of the plant nutrients exported from watersheds with eroded streambanks. Pre-treatment data are necessary to quantify reductions achieved with streamside fencing and streambank stabilization. The main thrust of the project is to provide pre-treatment data for N and P export from Cedar Run and Spring Creek to complement planned pre-treatment and post-treatment monitoring of sediment transport.

METHODS:

Site Description: Spring Creek is a 35 km long limestone stream in the Ridge and Valley physiographic province of central Pennsylvania. The watershed covers 381 km^2, with elevation differences between the mountain ridge and adjacent floor ranging from 182 to 305 m. Much of the valley is spotted with springs that are connected by a diffuse and extensive conduit system that carries groundwater. Average annual precipitation in the basin is about 1020 mm. Median daily discharge recorded at a USGS gage downstream of the study site during Water Year 1988 ranged from 0.753 m^3/sec in October to 2.1 m^3/sec in May (USGS 1990).

Table 1. Watershed characteristics

	Spring Creek	Cedar Run	Mackey Run
Drainage Area (km^2)	34.0	47.9	27.2
Length of Stream (km)	8.7	7.9	3.8
Length of Grazed Stream (km)	0.0	1.7	0.5
Agriculture (%)	22.0	66.7	51.5

This study was conducted on three sub-watersheds of the Spring Creek drainage (Figure 1). The sub-watersheds are the headwaters of Spring Creek, Cedar Run watershed and Mackey Run (Table 1). Spring Creek watershed above the gaging station at Oak Hall is approximately 8.7 km long and drains a 34 km^2 area (Table 1). Agriculture comprises 22% of land use in the headwaters drainage area. The predominant land uses are forest and urban/suburban. The streambanks and riparian areas are generally forested and in good condition. Residential and commercial construction are principle sources of nonpoint source pollutants.

Cedar Run drains a 48 km^2 sub-watershed and flows into Spring Creek at Oak Hall. Sixty-seven percent of this watershed is agricultural. The remainder is either forestland or residential development. About 27% of Cedar Run's 7.9 km perennial length is grazed by livestock and is considered degraded. While some property owners have made efforts to stabilize the streambanks by lining them with field stones, the pastures are grazed to the waters edge and livestock have complete access to the stream.

Mackey Run drains approximately 57% of the Cedar Run watershed (27.2 km^2) and flows into Cedar Run at Linden Hall. Recent development in the watershed has converted dairy farmland to smaller farmettes with horse pastures.

Meteorologic Site: Standard meteorologic data consisting of raingage, air and soil temperatures, wind speed and direction, and relative humidity were collected using standard procedures.

Stream Discharge: Stream stage was recorded at natural control gaging stations (Figure 1). A continuous flow monitoring station was established on Spring Creek and Cedar Run in August 1991. The criteria for gage location included ease of accessibility, and the exclusion of urban storm runoff. Stilling wells, modeled after the standard USGS design, were built to hold Stevens 1:1 ratio, 168-h water level chart recorders. A rating curve has been developed for these gaging station by measuring water velocity in the stream at different stream stages. All measurements were done 0.3 m apart on a transect perpendicular to streamflow, at a depth 0.6 times the total depth of the water at that point. This was done at least monthly at the stilling well sites. After twenty measurements were completed, the data were used to develop a quadratic regression of streamflow versus stage height to estimate discharge. The charts are digitized, edited, and

... were calculated by

Stream Sampling: Stream samples were collected during baseflow conditions three times a week at the gaging stations on Cedar Run, Mackey Run and Spring Creek and then analyzed for pH, chloride, nitrate-N, sulfate, total phosphorus, total nitrogen and suspended solids by standard methods (Table 1). Total concentrations were determined on unfiltered samples, and concentrations of dissolved constituents were measured for samples filtered through a 0.45 micron filter. All samples were preserved by chilling to 4C from time of collection to analysis. Baseflow samples were collected with a DH-81 sampler with a 3/16" nozzle following the depth-integrated, equal-width increment procedure of Ward and Harr (1990).

Laboratory procedures used to analyze the collected samples are outlined in Table 2.

Table 2. Analysis procedures used

Analyte	Procedure
Suspended Solids	EPA Method 160.2
Turbidity	EPA Method 180.1 (Nephelometric)
Total Phosphorus	EPA Method 365.3 SM 424.D
Total Nitrogen	Total Kjeldahl digestion w/ Ion selective electrode
pH	Glass electrode
Ortho phosphate	EPA Method 365.2
Nitrate, Chloride, Sulfate	Non-suppressed ion-chromatography Column: Wescan 269-013 Eluent: phthalic acid

Water samples were collected over the hydrograph during storms with Sigma Streamline 800SL automatic samplers. Intakes for the automatic samplers were positioned in the center of flow and samples were pulled into a length of perforated tubing that extends from the bottom to the surface of the stream. The samplers at Spring Creek and Cedar Run were programmed to collect a flow-weighted composite sample for each storm. The samplers were programmed to begin sampling when stream stage increased 5 mm, and to collect samples at specified volumes of flow. The collection interval was adjusted to have 20 or more samples composited per storm. Stage was measured with a pressure transducer and discharge volumes were calculated by integrating

discharge rates from provided rating curves. Since a rating curve had not been developed for Mackey Run, at the beginning of the project, the automatic sampler was programmed to collect discrete samples at constant intervals of time. Storm samples were analyzed for the same constituents and by the same methods as the baseflow samples. The mass flux of nonpoint source pollutants past the gaging station at Spring and Cedar was calculated by multiplying the volume of water discharged between sampling times by the average concentration over the interval.

Statistics: All Statistical procedures used SAS (1985) software. Pearson product-moment correlation was run on variables of interest. The General Linear Model was used to conduct analysis of variance to determine differences between the three streams for each variable. A homogeniety of slopes (covariate) model was also used.

Results:

Meteorologic Data: One meteorological site was used for the entire study area. Rainfall for the study period, November 1, 1993 to October 31, 1994 was measured to be 1225 mm. Monthly precipitation ranged from 21 mm in October 1994 to 181 mm in August 1994. Mean monthly temperatures for the study period ranged from -7.5C in January 1994 to 22.3C in July 1994 (Table 3).

Table 3. Meteorological data

Month	Precipitation (mm)	Mean Temperature (C)
November-93	136	4.38
December-93	55	-1.68
January-94	123	-7.45
February-94	96	-3.75
March-94	173	0.75
April-94	84	10.92
May-94	83	12.75
June-94	86	20.90
July-94	121	22.29
August-94	181	19.38
September-94	66	15.92
October-94	21	9.33

Stream Discharge: Stream gaging done during the study period confirmed the validity of the rating curve developed from 1991-1992 by Wohl (1993). Stream discharge was measured continuously at Spring Creek and Cedar Run between November 1, 1993 and October 31, 1994 (Figure 2). Measured discharge ranged from 0.16 m^3/s to 38.90 m^3/s at Spring Creek and from 0.10 m^3/s to 3.43 m^3/s at Cedar Run. The Spring Creek hydrograph represents a much flashier stream, where the stream stage increased rapidly during a storm and returned to baseflow conditions more rapidly than Cedar Run. The flashy nature of flow in Spring Creek can in part be attributed to impervious surfaces from road construction which parallel Spring Creek near the gaging station. Total discharge from Spring Creek and Cedar Run was measured as 23.26 and 11.72 million cubic meters, respectively. This volume of water is equivalent to 51% (625 mm) at Spring Creek and 21% (254 mm) at Cedar Run of the rainfall that fell during this period. The difference in discharge between the two watersheds cannot be attributed to differences in land use or stream condition. When constructing a water balance for a watershed, the difference between rainfall and discharge is usually either consumptive use or storage. Inter-watershed transfers of water, such as an intake for a water supply in one watershed with the corresponding water treatment plant outlet in an adjacent watershed are other reasons for differences between precipitation and discharge. Spring Creek, Cedar Run, and Mackey Run are underlain by karstic limestone with numerous springs and solution channels. In such geology, the boundaries of surface and subsurface watersheds often do not coincide. Water discharging from springs in one watershed may originate in other watersheds. Likewise, water flowing in a stream on this type of limestone may drain into the groundwater system and reappear in another watershed. Wohl (1993) found numerous sections of these streams which lost water to groundwater. Both of these water transfer processes operate in the larger Spring Creek watershed and are the likely sources of the difference in area-weighted discharge from Spring Creek and Cedar Run. This is not to suggest transfers directly from Cedar Run to Spring Creek. Another smaller source of the difference may come from greater errors in estimating discharge from Cedar Run than from Spring Creek during large runoff events in November 1993 and March 1994. Both streams were out of their banks during these events and their rating curves underestimate flow for such conditions. Discharge was underestimated by a greater amount at Cedar Run, because Spring Creek is constrained by steeper near-stream slopes at the gaging station than is Cedar Run. The reported volumes discharged underestimate actual discharge by an unknown amount because of the two large runoff events. The uncertainty in total discharge estimates is likely less than 5%. Mackey Run was not a part of the original study design. However, a gaging station was established at the confluence of Mackey and Cedar Runs to better determine the source of sediment and chemicals in the Cedar Run catchment. The rating curve for Mackey Run is still under development. Consequently, mass discharge of NPS pollutants will not be calculated, and

only their concentration at Mackey will be compared to Spring Creek and Cedar Run.

Suspended Solids: The concentration of suspended solids was determined for all storm and baseflow samples collected during the study period (Table 4). Turbidity is often used as a surrogate for suspended solids. Consequently, turbidity was measured on about 1/3 of all collected samples to develop a predictive relationship between turbidity and suspended solids.

Table 4. Average suspended solids and turbidity for Spring Creek, Cedar Run and Mackey Run.

Stream	Number of Samples	Suspended Solids (mg/l)	Turbidity (ntu)	Suspended Solids (kg/ha/yr)
Spring Creek	204	13.32a	14.21	136.48
Cedar Run	188	24.01b	20.16	116.55
Mackey Run	182	21.59b	23.05	-

Suspended solids and turbidity for all streams combined were significantly correlated (P<0.0001) with Pearson correlation coefficient of 0.91. The correlation analysis was also performed by sample type (storm or baseflow) and by stream. Suspended solids and turbidity were still significantly correlated when samples collected during baseflow and storm conditions were analyzed separately (P<0.0002), and when samples collected from the different streams were analyzed separately (P<0.0001). The correlation coefficients for storm and baseflow samples were 0.92 and 0.29, respectively, indicating that much more of the variability in suspended solids could be explained by variations in turbidity for the storm samples than for the baseflow samples. Correlation coefficients for the streams ranged from 0.84 (Spring Creek) to 0.94 (Mackey Run), indicating that, for each of the streams, greater than 70% of the variability in suspended solids could be explained by linear variations in turbidity. Since the correlations were significant, regression analysis with turbidity as the dependent variable were performed for each of the streams. Linear and quadratic terms were significant (P<0.0001) for Spring Creek and Mackey Run, while only the linear term was significant (P<0.0001) for Cedar Run. When linear components were analyzed, from a homogeneity of slopes model, we concluded that the regression relationships were not different. Consequently, a single relationship could be used to describe the suspended solids - turbidity relationship for the three streams.

An analysis of variance revealed significant differences in the concentration of suspended solids ($P<0.01$) among the streams. Suspended solids were significantly less concentrated in Spring Creek compared to Cedar or Mackey Run (Table 4). This corresponds to expectations from land use and length of degraded stream bank within the watersheds (Table 1). Faster moving water has more energy available to suspend and transport particles. This is seen in the coincident pattern of discharge and suspended solids for both Spring Creek and Cedar Run (Figure 3 a,b). Significant correlations were found between suspended solids and discharge and between suspended solids and log(discharge) ($P<0.0001$). While both of the relationships were significant, Pearson correlation coefficients of 0.27 and 0.23 show that little of the variation in suspended solids concentration is explained by discharge alone.

The mass flux of suspended solids at each of the gaging stations was calculated by multiplying the volume of discharge between times when samples were collected by the average concentration of the samples collected at the beginning and end of the sampling interval. The mass of sediment discharged during sampling intervals was then summed and divided by the drainage area of each catchment to give the total sediment load (Table 4). Spring Creek was not expected to carry a greater area-weighted sediment load than Cedar Run. The Spring Creek drainage has less agriculture and the stream banks are in better condition than for Cedar Run (Table 1). Wohl and Carline (1995) measured a substantially smaller suspended solids load from Spring Creek than Cedar Run for the period October 1, 1991 to September 31, 1992. The differences between our results and Wohl and Carline's are due to greater differences in water flow between the streams and substantially greater suspended solids concentrations in Spring Creek. The area-weighted volume from Spring Creek was only 2.0 times that of Cedar Run during 1991-1992 compared to 2.5 times during 1993-1994. Wohl and Carline (1995) reported suspended solids concentrations of 5 and 25 mg/l for Spring Creek and Cedar Run, respectively. His value for Cedar Run is close to the concentration we measured (Table 4). However, the concentration Wohl and Carline (1995) measured at Spring Creek during 1991-1992 was approximately 1/3 of the concentration we measured. We attribute the greater suspended solids concentration to a greater level of commercial and residential construction, some of it quite near to the stream gaging station.

The sediment load we measured at Spring Creek and Cedar Run fall between that measured for forest (Lietman et al., 1983) and ungrazed pasture (Owens et al., 1989), but are an order of magnitude less than they measured for grazed pastures. Both of these researchers measured sediment load directly downstream of the disturbed area, and were essentially measuring the effects of a single land use - management practice combination. Our measurements were made at the outlet of a larger watershed with mixed land uses and management practices. Water

originating from land with less erosive practices dilutes the sediment load from grazing lands with unbuffered streams. The variation in sediment load from the Spring Creek watershed, with no grazing and the small differences between Spring Creek and Cedar Run may make it difficult to document changes due to improved streambank conditions. Long-term monitoring will likely be required.

The mass discharge of suspended solids was separated into storm event and baseflow periods. In excess of 90% of total suspended solids load was associated with storm events for both Spring Creek and Cedar Run. The largest event, the snow melt in March, accounted for approximately 50% of the total load, and the three largest events totaled 75 and 70% of the yearly sediment load in Spring Creek and Cedar Run, respectively. Current management is sufficient to control runoff during small events. Reductions in suspended solids load will require the implementation of techniques to reduce the energy of runoff during major events.

Chemistry: Nitrate-N, chloride, sulfate, ortho-phosphate, total phosphorus (TP) and total kjeldahl nitrogen (TKN) were measured on all collected samples by the standard procedures listed in Table 2. Total phosphorus and TKN were determined on unfiltered samples all other constituents were determined on samples filtered through a 0.45 micron filter. Due to TP and TKN concentrations below detection in most baseflow samples, baseflow samples were composited by week before TP and TKN analysis. At this writing, too many total phosphorus and TKN results have not been received from a contract lab to adequately describe their results. Nitrate-N, chloride and sulfate concentrations ranged from 0.8 to 8.0, 3.2 to 29.6, and 6.2 to 28.2 mg/l, respectively. Means and standard errors for each of the streams are shown in Tables 5 a,b &c.

An analysis of variance showed that significant differences in nitrate-N, chloride, and sulfate concentration exist among the three streams ($P<0.0001$). A pair-wise comparison further showed that the streams were all different from each other in each of the constituents ($P<0.05$). The pattern of nitrate-N concentrations, Spring Creek<Mackey Run<Cedar Run, was expected from watershed characteristics (Table 1). The Spring Creek drainage above the gaging station has the least agriculture and has the least degraded streambanks. Both Mackey Run and Cedar Run catchments have substantial agriculture. However, the agriculture in the Mackey Run catchment has undergone a conversion from dairy to farmettes with a few horses. The greater intensity of agriculture in the Cedar Run catchment results in higher inputs of nitrogen which are reflected in higher nitrate-N concentration at the catchment outlet. Sulfate patterns frequently mimic those of nitrate-N, as they do for these three streams. No ancillary data were collected to determine specific sources of the differences in sulfate concentration. The pattern of chloride

concentrations, Mackey Run<Cedar Run<Spring Creek, reflects the length of improved roadways in the watersheds and, consequently, the amount of materials applied to remove snow and ice.

Table 5a. Nitrate-N concentration in and export from Spring Creek, Cedar Run and Mackey Run.

Stream	Number of Samples	Nitrate-N (mg/l) Mean	Std Err	Nitrate-N (kg/ha/yr)
Spring Creek	204	2.44a	0.05	14.48
Cedar Run	188	4.43b	0.06	13.93
Mackey Run	182	3.93c	0.06	-

Table 5b. Chloride concentration in and export from Spring Creek, Cedar Run and Mackey Run.

Stream	Number of Samples	Chloride (mg/l) Mean	Std Err	Chloride (kg/ha/yr)
Spring Creek	204	12.77a	0.35	71.81
Cedar Run	188	10.15b	0.36	31.99
Mackey Run	182	6.41c	0.37	-

Table 5c. Sulfate concentration in and export from Spring Creek, Cedar Run and Mackey Run.

Stream	Number of Samples	Sulfate (mg/l) Mean	Std Err	Sulfate (kg/ha/yr)
Spring Creek	204	18.02a	0.18	122.09
Cedar Run	188	22.11b	0.20	72.14
Mackey Run	182	19.77c	0.21	-

When plotted against time (Figure 4 a,b), nitrate-N concentrations generally decrease during storm events at both Spring Creek and Cedar Run. The effect is more easily seen for Cedar Run because baseflow nitrate-N concentrations were more constant over time than for Spring Creek.

It is apparent that large runoff events exhibit a markedly reduced nitrate-N concentration, but smaller storms (February and July) also show substantial reductions in nitrate-N concentration. This pattern of reduced concentration with higher discharge is in contrast to the pattern of suspended solids concentration. The majority of nitrate-N enters streams when groundwater discharges. The drop in nitrate-N concentration during storms results from a dilution of discharging groundwater by more dilute overland flow. Sulfate and chloride exhibit similar patterns for the same reason. A correlation analysis was performed to determine if nitrate-N, chloride, and/or sulfate were significantly correlated with stream discharge. The concentration of all three anions were significantly, negatively correlated ($P<0.0001$) with discharge and log(discharge) at Spring Creek. Pearson correlation coefficients were slightly higher when concentration was correlated with log(discharge). They ranged from -0.63 for nitrate-N to -0.36 for chloride indicating that while the correlations were highly significant, discharge alone explained no more than ~1/3 of the variability in anion concentration. At Cedar Run, only nitrate-N was significantly correlated ($P<0.05$) with discharge, and nitrate-N and sulfate were significantly correlated with log(discharge). Pearson correlation coefficients of -0.18 and -0.20 indicate that discharge explains little of the variability in nitrate-N concentration at Cedar Run.

Area-weighted mass fluxes of nitrate-N, chloride and sulfate were greater from the Spring Creek drainage above Oak Hall then from Cedar Run. This despite significantly greater concentrations of nitrate-N and sulfate in Cedar Run. The reversal between relative concentration and area-weighted mass flux occurs because of the 2.5 times greater area-weighted water exported from Spring Creek noted above. If the difference in water export results from inter-watershed exchanges of groundwater, as speculated, the source of dissolved solutes (e.g., nitrate-N, chloride, sulfate) measured at the gaging station will not be precisely known. As a corollary, changes in solute loss resulting from management changes will be more difficult to discern and attribute to specific causes. This is somewhat different from the situation with suspended solids. The exchange of groundwater between watersheds effects sediment transport by changing the water regime in the watershed, but it is unlikely to effect the source of the sediment (i.e., sediment isn't transported between watersheds in subsurface flow). The transfer of water between watersheds reduces the energy of the remaining flow in the channels and hence its' capacity to entrain particles. Antecedent moisture conditions will also be different and, therefore, initial contributing areas for sediment will also be different because the water transfer.

Ortho-phosphorus concentrations ranged from below the detection limit (0.005 mg/l) to 0.069 mg/l. The distribution of ortho-phosphorus concentration is much different than the other constituents covered above. The concentration of approximately 85% of the samples analyzed was below the detection limit (Figure 5). Consequently, mean values are not helpful, and the median

concentration was below the detection limit for each of the streams. Ortho-phosphorus concentration and discharge were not correlated when the data from Spring Creek and Cedar Run were combined. When the data were analyzed separately, discharge and ortho-phosphorus were significantly correlated ($P<0.008$) in Spring Creek, while the data for Cedar Run were not correlated. Mass fluxes of ortho-phosphorus were calculated by arbitrarily setting concentrations below the detection limit to 1/2 the detection limit. When this was done, ortho-phosphorus exported from Spring Creek and Cedar Run were 0.05 and 0.02 kg/ha/yr, respectively. The ratio of ortho-phosphorus export from the watersheds is the same as the ratio of water export. The ratios were expected to be close based on the similarity in the frequency distribution of ortho-phosphorus concentration between the watersheds (Figure 5).

Summary:

Sediment and plant nutrient export were measured from three watersheds with from 22 to 87% agricultural land use, for 1 year, as a prelude to streambank fencing and stabilization. The sub-catchments of the Spring Creek watershed in Centre County, Pennsylvania are underlain by karstic limestone, range in size from approximately 27 to 48 km^2, and have up to 22% of their streambanks in a degraded condition. Average concentration of suspended solids, and nitrate-N ranged from 13 to 24 mg/l and 2.4 to 4.4 mg/l, respectively, for the watersheds. Phosphorus concentrations were skewed to the left, with approximately 85% of the samples having phosphorus concentrations below detection. As expected, the watershed with the most agriculture and greatest length of degraded streambank had the highest concentration of sediment and nitrate-N at the watershed outlet. However, when concentrations were merged with stream discharge to calculate area-weighted pollutant discharges, the watershed with the least agriculture and least degraded streambanks had the greatest area-weighted pollutant discharge. The difference in pollutant discharge results from a 2.5-fold greater stream discharge from the watershed with less agriculture. In areas with karstic limestone, it is common for groundwater recharged in one catchment to discharge to a stream in another catchment. The quantities of stream discharge measured during this study suggests that a sizable fraction of groundwater recharge is unaccounted for at the catchment outlet in the watershed with the most agriculture. Previous work in these watersheds showing that sections of these streams lose water to groundwater support this conclusion. An objective of this research was to provide pre-treatment information from which to assess the impact of streambank fencing and stabilization on NPS pollutants. The impact of fencing and bank stabilization within the small catchments can be determined from pollutant concentrations. The concentration data collected here provides an appropriate baseline to assess within-catchment effects. The impact of any management change on regional water quality (e.g., the Chesapeake Bay) depends on the mass discharge from as well

as the pollutant concentration at the catchment. The unanticipated pattern of pollutant discharge among the watersheds, attributed to inter-watershed transport of groundwater, makes the assessment of fencing and bank stabilization on larger-scale water quality a more difficult, longer process for this type of watershed.

Literature Cited:

Lietman, P.L., J.R. Ward and T.E. Behrendt. 1983. Effects of specific land uses on nonpoint sources of suspended sediment, nutrients, and herbicides - Pequea Creek basin, Pennsylvania 1979-1980. US Geological Survey, Water Resources Investigations Report 83-4113.

Owens, L.B., W.M. Edwards, and R.W. Van Keuren. 1989. Sediment and nutrient losses from an unimproved, all-year grazed watershed. J. Env. Qual. 18:232-238.

Owens, L.B., W.M. Edwards, and R.W. Van Keuren. 1993. Stream fencing reduced sediment loss from a pastured watershed. Agronomy Abstracts. page 44.

Rinne, J.N. 1988. Grazing effects on stream habitat and fishes: Research design considerations. North American Journal of Fisheries Management 9:446-457.

SAS. 1985. SAS stat guide for personal computers, version 6. SAS Institute, Inc., Cary, NC.

USGS. 1990. Water resources data Pennsylvania water year 1988. Volume 2 Susquehanna and Potomac River Basins. USGS Water Data Report PA-88-2-1990

Ward, J.R., and C.A. Harr. 1990. Methods for collection and processing of surface water and bed-material samples for physical and chemical analyses. U.S. Geological Survey, Open-File Report 90-140.

Wohl, N.E. 1993. An ecological assessment of sediment loads from three streams in the Spring Creek Basin, Centre County, Pennsylvania. MS thesis, The Pennsylvania State University, University Park, Pa. pp: 117.

Wohl, N.E., and R.F. Carline. 1995. Relations among riparian grazing, sediment loads, macroinvertebrates, and fishesin three Central Pennsylvania Streams. Can. J. Fish. Aquat. Sci. (In Press)

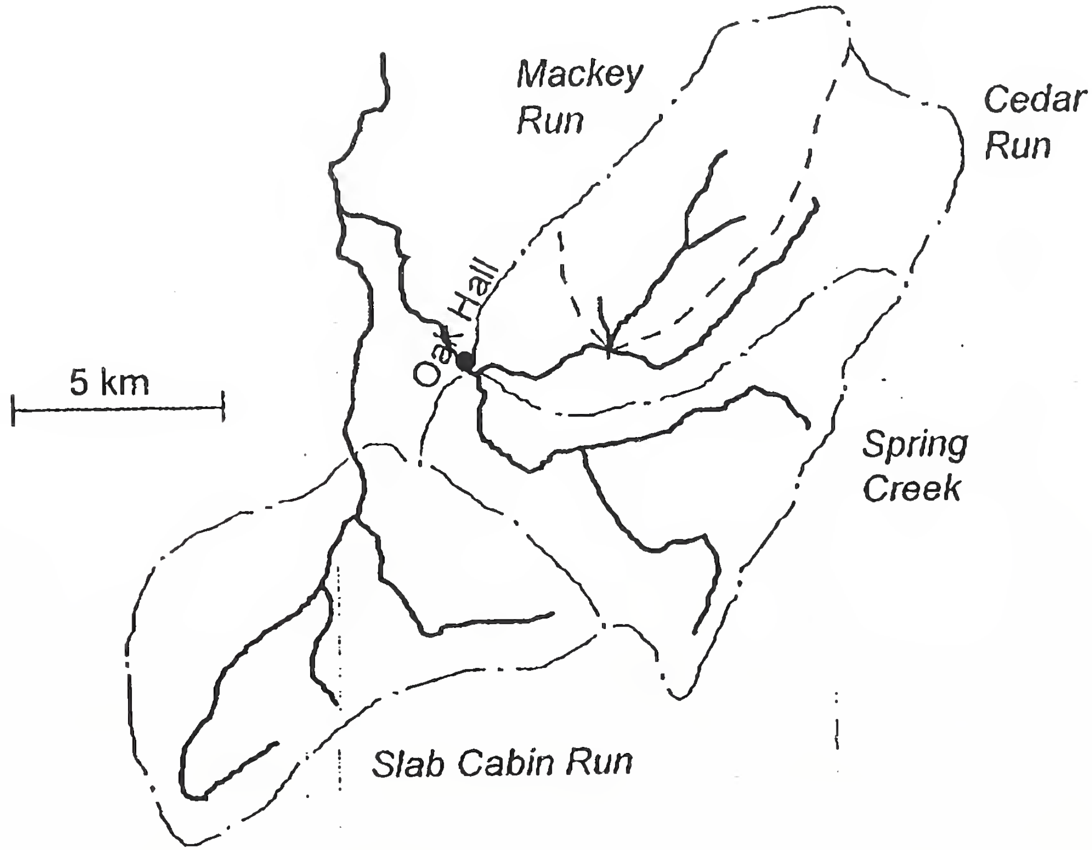

Figure 1. Boundaries of Spring Creek, Cedar Run, and Mackey Run watersheds.

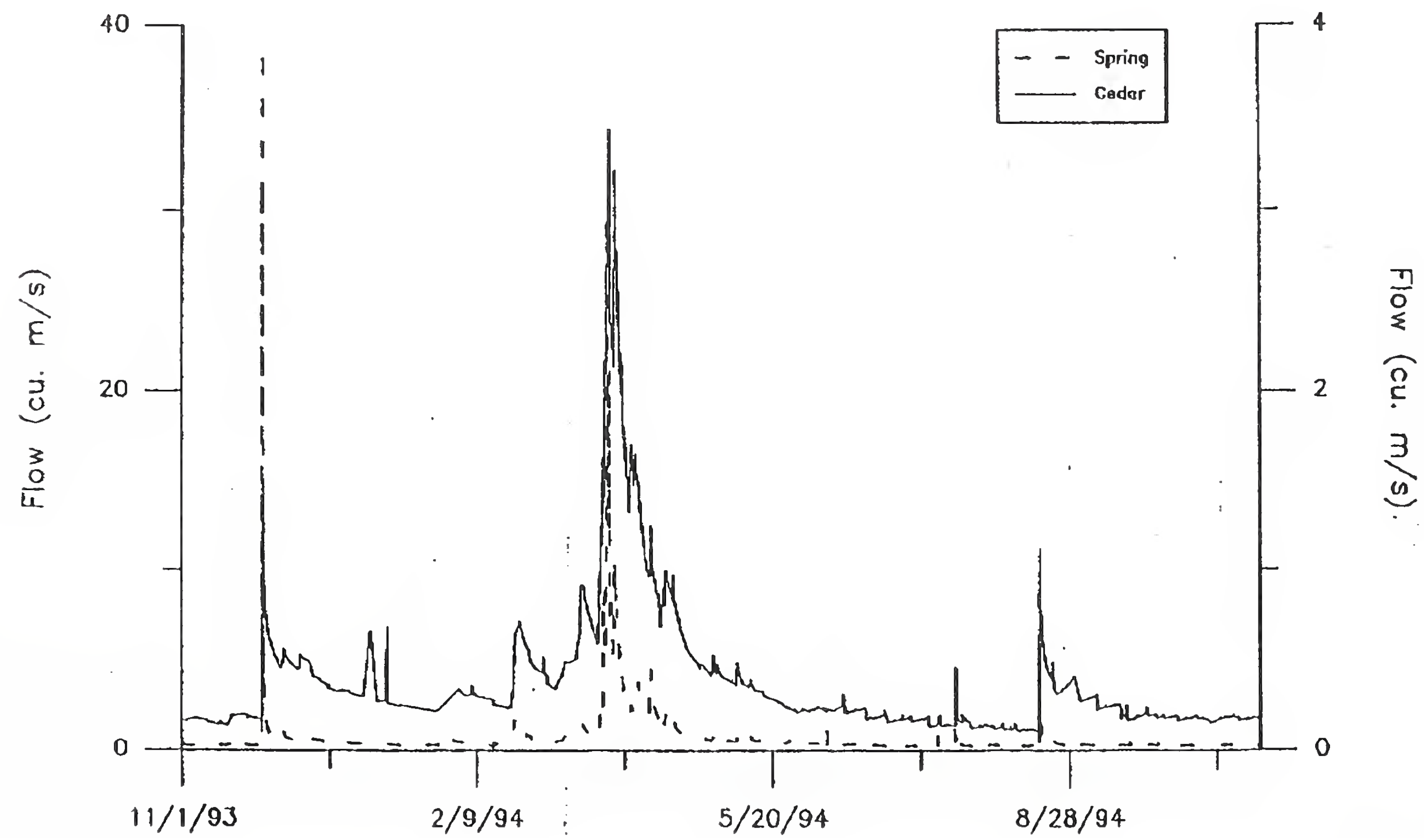

Figure 2. Discharge at gauging stations on Spring Creek and Cedar Run.

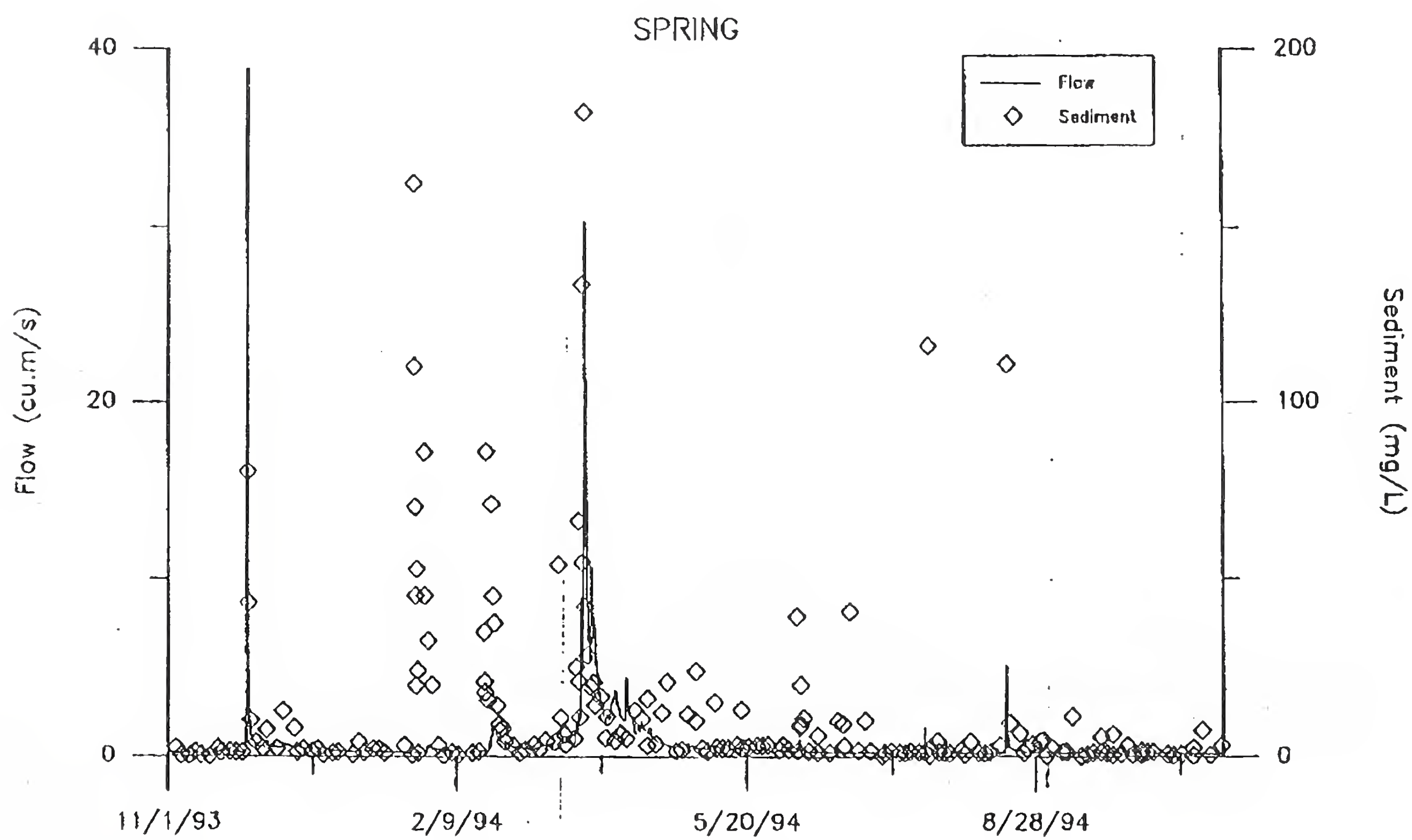

Figure 3. Suspended solids concentration superimposed on discharge at Spring Creek gauging station.

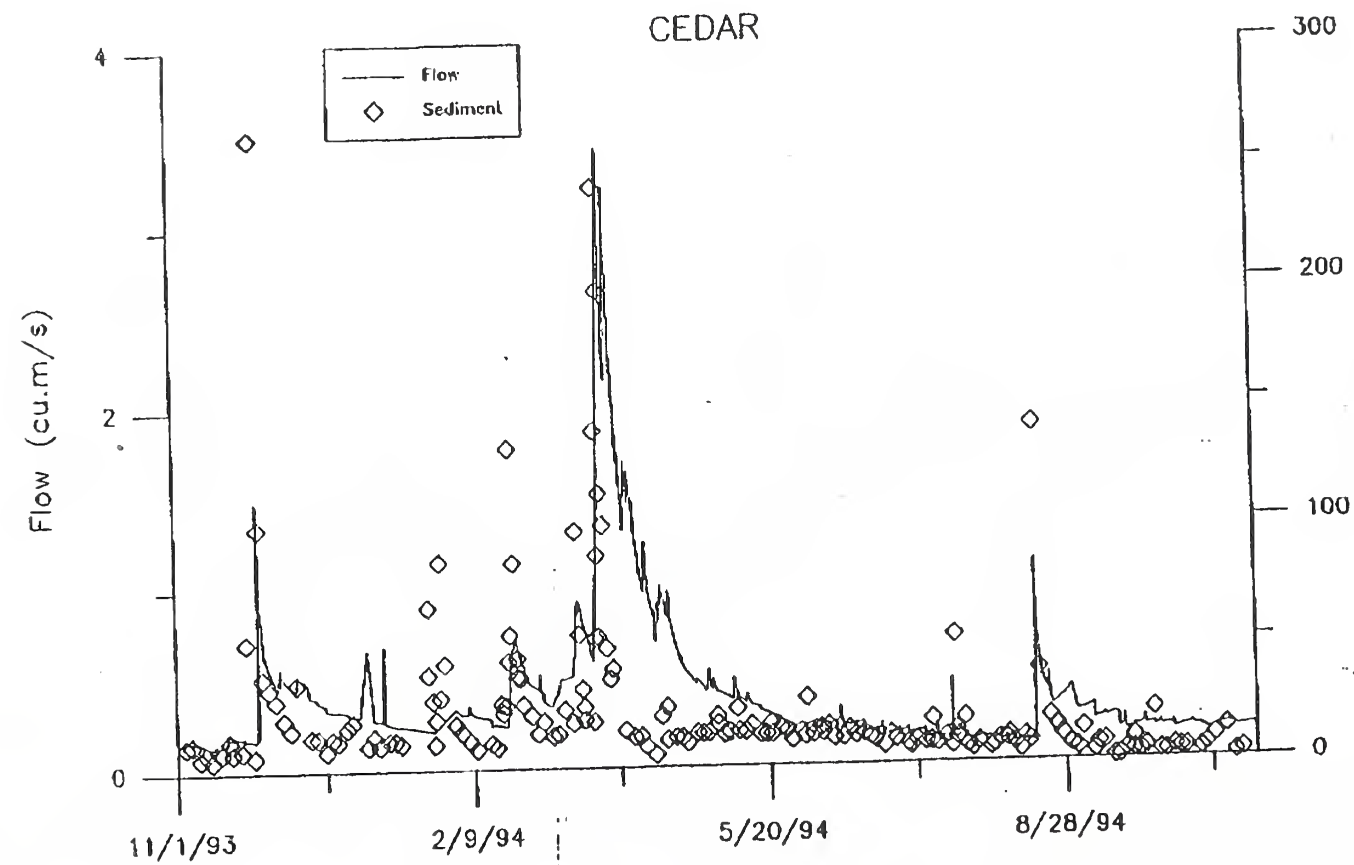

Figure 4. Suspended solids concentration superimposed on discharge at Cedar Run gauging station.

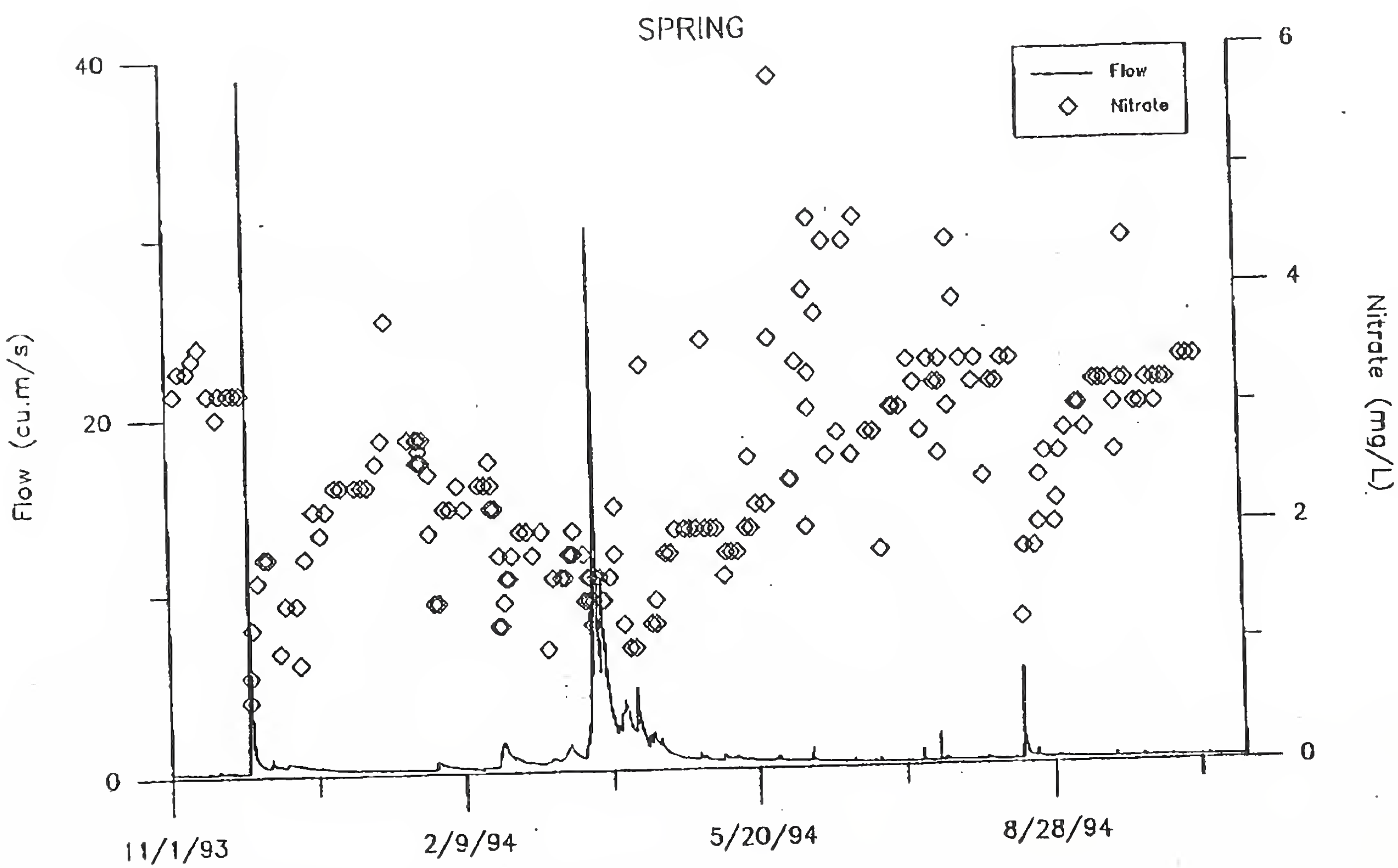

Figure 5. Nitrate-N concentration superimposed on discharge at Spring Creek gauging station.

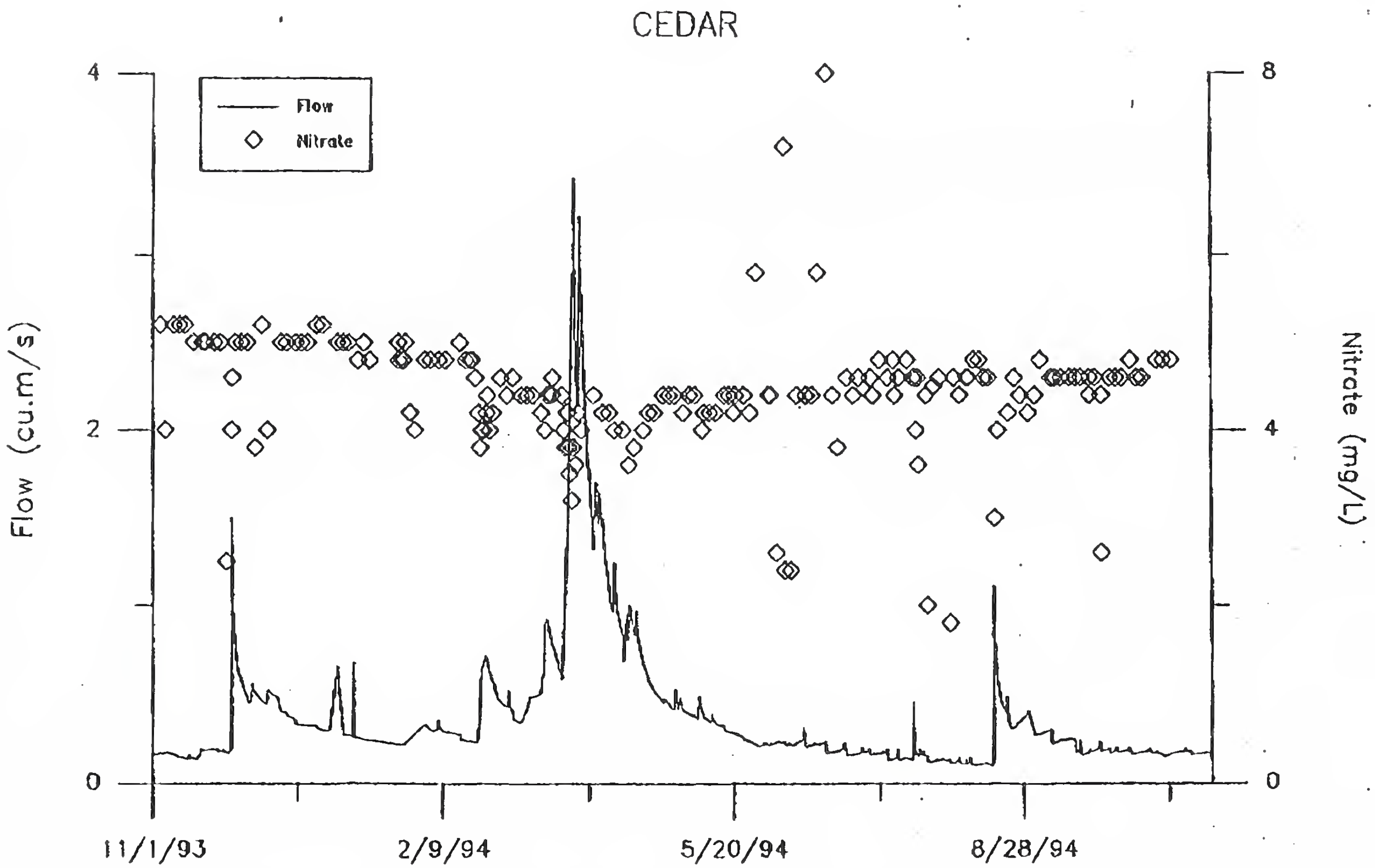

Figure 6. Nitrate-N concentration superimposed on discharge at Cedar Run gauging station.

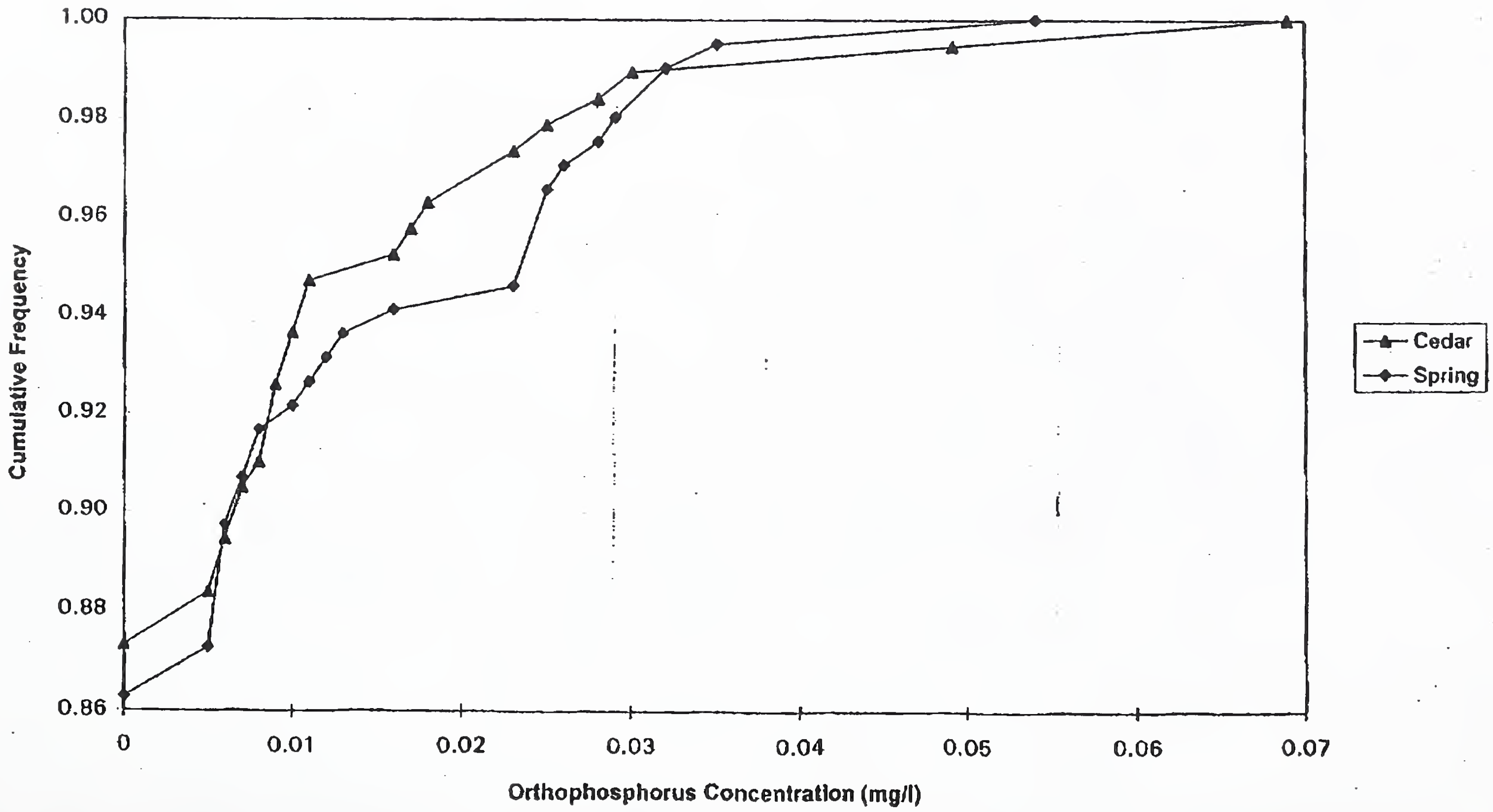

Figure 7. Distribution of phosphorus concentration at Spring Creek and Cedar Run.